Acoustical Technology for the Study of Marine Organisms

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LONG-TERM GOAL

The long-term goal of our research is to improve our ability to observe the ocean's plants, animals and their physical and chemical environment at those critical scales which control how they live, reproduce and die.

OBJECTIVES

Chronic undersampling of the marine environment, including both biological and physical components, has been, and remains a major block to understanding how marine ecosystems function and how they respond to changes, whether natural or anthropogenic. Consequently, data-based models that accurately predict local variations abundances of plant and animal life in the sea are rare or do not exist at all. Such models would be invaluable in predicting variables such as acoustical and optical scattering in areas of tactical interest to the Navy. Our research directly addresses the root of this problem by attempting to advance acoustical technology as an aid in measuring spatio-temporal distributions of a variety of marine organisms in relation to the physio-chemical ocean environment.

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APPROACH

Our research has multiple focus areas. The first involves our continuing participation in a multi-investigator experiment designed to examine and quantify the characteristics of a ***Critical Scale*** phenomenon that we are generically calling "thin layers". This phenomena, which has been observed in both littoral and open-sea environments, can potentially dominate or even control flows of biomass and energy between scales that are critical for individuals and those that are crucial for populations. Gaining an adequate understanding of the processes that take place at these critical temporal and spatial scales can ultimately impact the success of attempts to model a population's temporal dynamics and spatial structure. Based on our observations, it appears that "thin layers" in a variety of observable ocean quantities (e.g., temperature, density, phytoplankton, oxygen, zooplankton) may play an important role in the functioning of many coastal marine ecosystems.

During the summer and fall of 1998 we participated in a multi-investigator program in a small, shallow fjord at East Sound, WA. The "thin layers" project is a cooperative research effort involving scientists from Marconi -- formerly Tracor (Holliday, Greenlaw, McGehee), the University of Rhode Island (Donaghay, Rines, Dekshenieks, Gifford, Smith), Johns Hopkins University (Osborn), Oregon State University (Cowles, Sullivan, Zaneveld), the University of Washington (Perry), the Naval Research Laboratory / Stennis Space Center (Weidemann), the University of Southern California (Pieper), and the University of California at Santa Barbara (Alldredge, MacIntyre, Case/Herren). As a key part of this field experiment, we used a number of high resolution, high frequency acoustical instruments to examine the zooplankton response to optically detected phytoplankton layers (~10 cm thickness). Data from these sensors were also used to direct conventional sampling devices (pumps and siphons) to those layers in order to examine their constituent parts. We are currently analyzing data and preparing publications based on the data we collected during these experiments

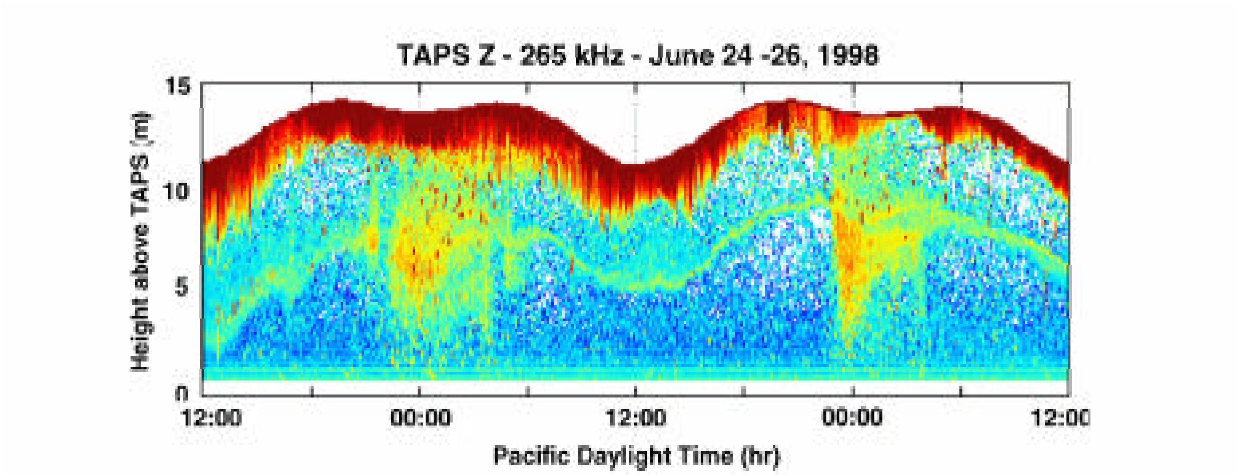
Our work in East Sound, and that of our co-PIs, produced much more exceptionally high quality data than we had anticipated. It also resulted in the observation of some welcome, but unexpected, natural phenomena with direct Navy relevance (see results below). As a result, our emphasis has shifted a bit and we are applying additional effort to the analysis and publications effort for the East Sound data set at the expense of the second area of research we are addressing in this three-year research effort. As the work on the East Sound data winds down, we plan to renew our emphasis on this second area, which involves the investigation of a new acoustical method for studying organisms in aquatic ecosystems. Over several years, we have successfully exploited the spectral frequency dependence of acoustical backscattering on the size and abundance of water column zooplankton, micronekton and fish. Our multi-frequency methods are now being used by a variety of investigators in fields ranging from fisheries to biological oceanography. We have also just begun to apply them to the examination of the benthos. While we are convinced that there remains much to be gained by the further development of bioacoustics in the spectral domain, we are working to open an additional dimension to exploitation -- that dimension is the 3-D multi-static, azimuthal dependence of scattering from marine organisms. This work encompasses investigations of several new approaches to the generic inverse problem for bioacoustics, some of which may be applicable to problems in classification and identification for both biotic and abiotic acoustic targets.

WORK COMPLETED

We have completed the first two levels of processing for our data from all of the sensors we deployed in the 1998 East Sound field work with the "thin layers" group. These data have been distributed to all of the particpants and selected segments presented at AGU Ocean Sciences and ASLO meetings. Selected parts of the data have been presented at the Naval Undersea Warfare Center's Newport laboratory and at a joint meeting of the NAS/NRC's Commission on Geosciences and the Environment and the Canadian National Environmental Research Council. We have participated in several data synthesis meetings of the thin layers group and continue to provide data to various PIs in this group for use in papers that are in preparation. We have also contributed data and information for inclusion in the thin layers section of the ***Critical Scales*** web page listed in the header above.

Although the principal emphasis of our work has involved the processing of our data from the East Sound thin layers experiment, we have begun the work that we hope will lead to the exploitation of azimuthal dependencies in scattering from zooplankters. We have developed the software and hardware needed to measure the azimuthal and spectral dependence of scattering from millimeter-size (small crustacean-sized) targets. We have made measurements of the scattering for several millimeter-sized artificial targets and have also made measurements of the azimuthal reflectivity of two preserved euphausiids.

RESULTS



Above, we illustrate only a few of the processes and patterns that we observed with one of three up-looking moored six frequency TAPS deployed from early June through mid-August of 1998 in East Sound, Orcas Is., WA. The TAPS were moored in the middle of the water column, nominally 12 m above the bottom at each corner of a triangle, 300 m on a side. Data from each instrument were collected at one minute intervals. The vertical resolution was 12.5 cm. The data were cabled to shore, where they were stored on a disk and forwarded immediately via an RF link (provided by OSU) to the R/V Henderson, which served as a platform for a variety of process studies being executed by our co-PIs in the thin layers experiment. Since we left the TAPS array in place for several months after we left East Sound, the data were also automatically placed on a server, where they could be accessed via the

Internet. The Henderson was moored on the west side of the triangular TAPS array. Scientists on the ship were able to use these data to follow the dynamics of the thin layers and design their sampling protocols with an accurate, timely picture of the environment that they were sampling. The depths of the scattering structures often changed rapidly, and as the thin layers were often only 10 - 30 cm thick, real-time access to information such as that displayed above was a critical contribution to the experiment. In the TAPS data illustrated above, the height of the surface above the TAPS can be seen to vary with the semi-diurnal tide. High levels of scattering were observed just under the sea surface, even though the wind speed was below 5 knots during the entire period (below 1 knot from 18:00 on the 25th until 07:00 on the 26th) and no whitecaps were observed. The "plumes" of scattering that extended into the water column from the surface were visually correlated with the advection of surface slicks (apparently Langmuir circulation) over the TAPS array. A thin layer was present during the entire period and varied in depth from nearly 9 m to less than 5 m. The nights at this latitude and time of year were short, with sunset occuring at about 21:18 and sunrise at 05:10. Two distinct types of night-time vertical migrations were observed, one from near the surface down to the vicinity of the pycnocline and the thin layer, and the other from below the TAPS up to the region near the pycnocline and the thin layer. The thin layer and the pycnocline did not always coincide, with divergence occuring during times of rapid changes in the depth of the pycnocline. Discrete targets consistent with those expected when individual fish were present over the TAPS could be seen both near the thin layer and in the upper mixed layer during the night. This is consistent with the schooling / dispersal patterns of the juvenile herring known to be abundant in the area.

IMPACT/APPLICATION

Observation of aquatic animals in their natural environments remains a major challenge in both biological oceanography and limnology. Critical processes in feeding, reproduction, growth and predation in small zooplankton occur at scales from fractions of millimeters up to scales which match the ambits of individuals. It is often difficult to reproduce all essential features of the marine environment in the lab, where observation of small scale processes is more tractable than at sea. Therefore, there is continuing interest in improving our ability to observe and quantify *in situ* spatial and temporal changes in the distribution and abundance of zooplankton in relation to natural physical, chemical and other biological fields.

Understanding the distributions of small scale structures, their patterns and the processes that lead to their formation and dissolution must preceed modeling and prediction of their occurrence and subsequent impacts on underwater visibility, water column optical properties and underwater acoustical scattering.

In addition to our science objectives, our research efforts are adding to a base of knowledge that impact the following areas with direct Naval relevance: 1) the performance of high-frequency sonars; 2) the performance of high-speed vehicles in the littoral; 3) the fine- and micro- scale vertical distribution of small crustaceans, including those that exhibit bioluminescence; 4) temporal variations in seabed roughness (impact on the scattering and penetration of sound into the seabed); 5) underwater visibility; and; 6) the performance of systems used for bottom mapping in shallow water.

TRANSITIONS

During the last decade, we have developed a variety of new multi-frequency acoustical technologies for use by fisheries scientists and biological oceanographers. Our participation in the thin layers field work and in the on-going data synthesis with the "thin layers" principal investigators is a part of our continuing education program in the use of these new methods. Direct participation in such programs is intended to assure a transition of these technologies to a broad range of scientists working with zooplankton in marine and limnological ecosystems. As a part of this effort to make this powerful new technology available to a wide spectrum of scientists, during the last year we provided TAPS instrumentation to an ONR NOPP project (LOOPS), working with Robinson (Harvard); Levine (NUWC Newport); Rothschild (UMass); Patrikalakis, Chryssostomidis, Schmidt and Bellingham (MIT); Dickey (UCSB); Porter (JHU/APL) and Sherman (NOAA). An NSF / LMER project at CEES (with Roman, Houde, Boicourt and Boynton) also continues to make effective use of TAPS data. Overseas, Dr. Anne Lebourges (ORSTOM) is using a TAPS to describe the lower level trophic structure for a population of tuna that live in the equatorial Atlantic. We also continue to support a variety of other PIs in the US in applications of TAPS and other multi-frequency technologies to their own science programs (e.g, Mark Berman (NOAA/NMFS), Peter Ortner (NOAA/AOML), Sharon Smith (RSMAS / Miami), Jeff Napp (NOAA/AFSC) and Gordie Schwartzman (APL/UW).

We are currently discussing a project that would lead to the instrumentation of one of the Navy's test ranges with one or more of our profilingTAPS.

RELATED PROJECTS

We will be using several TAPS in cooperation with Peter Jumars (Univ. of Maine) and Jill Schmidt (Univ. of Washington) to study the emergence of benthic animals into the water column during an ONR multi-investigator program in the Gulf of Mexico during the fall of 1999 (SAX-99). This program focuses on impacts that benthopelagic animals have in changing the bottom topography at millimeter scales, a process that may partially explain an anomalous penetration of sound into the seabed at lower acoustical frequencies than are used by the TAPS. Strong emergence / re-entry of large numbers of small crustaceans were first observed acoustically during our work in West Sound, WA and then again in East Sound, WA (in 1996) as an unexpected benefit of observations carried out under this contract.

The end of our deployment of the TAPS array in East Sound coincided, by design, with an NRL program in which overflights were made of the sound with a suite of hyperspectral optics. During that period, we accessed the data from our TAPS via the Internet and forwarded our observations to the investigators that remained in East Sound to support the overflight program. Two reports were made by e-mail each day on the subsurface structures we observed at the site of the TAPS array.

We are also using our TAPS technology to define the distribution of lower trophic levels in the Mediteranean Sea, where our interest is ultimately in whether the use of low frequency sound sources will cause the redistribution of marine mammals. This project (SOLMR - Sound Oceanography and Living Marine Resources) is with scientists from SACLANTASWCTR, the U. of Pavia, WHOI, NMFS and ICRAM.

PUBLICATIONS

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